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ABSTRACT

SOME PROBLEMS OF PIPELINE ROUTE SELECTION

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F.E. Culvern F. ASCE

G.H. Watson M. ASCE

J.E. Wilson P.E., API

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The present-day ecological movement has presented new problems to the pipeline engineer. No longer is the most direct route the most economical route to build the pipeline along.

Avoidance of critical areas to ensure continued wildlife preservation and reduce apparent hazardous conditions to the population are key considerations today.

Construction of long large diameter pipelines in the Sub-Arctic and Arctic requires mile by mile geotechnical investigation of the subsoil context. The degree of permafrost soils and the proper identification of physiographic divisions of sub-surface conditions will require the expenditure of considerable amounts of monies and efforts before the most economic route can be selected.

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F.E. Culvern[1] F. ASCE
G.H. Watson[2] M. ASCE
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INTRODUCTION

The problem of pipeline route selection arises from the fundamental problem of having a commodity at one place and being desirous of moving it in a pipeline to another place. It will be noted that this presentation is concerned only with the problems of route selection or route alignment and does not cover the broad aspect of pipe location. Route or alignment is defined as the projection of the pipeline onto a horizontal plane or onto a geodetic surface and does not cover its location in the vertical direction.

Also structural design and methods of construction are excluded except as they may affect alignment.

The general procedure for route selection is treated first, followed by some special problems which may occur in non-wilderness areas, wilderness areas, and arctic areas, which are usually wilderness areas.

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[1]Partner, Butler-Culvern & Associates, 4815 S. Harvard Avenue, Tulsa, Oklahoma 74135

[2]Senior Geotechnical Engineer, Acres Consulting Services Limited 990 - One Palliser Square East, Calgary, Alberta T2G 0P6, Canada

[3]Associate, Butler-Culvern & Associates, 4815 S. Harvard Avenue, Tulsa, Oklahoma, 74135

OBJECTIVES

The objective of the presentation is to bring to the attention of those engineers who are interested in the problems of the pipeline engineer, a brief orderly description of the basic steps required in route selection. Then to present some of the special problems which must be solved. It is not intended as a handbook on pipeline location. It is intended to outline some of the problems of alignment, particularly those which are the result of the new interest in environment protection and those which arise from pipelines in Arctic regions.

LOGICAL STEPS IN IMPLEMENTING AN ALIGNMENT

(a) Locate the line end points, both geographically and on the state or states plane coordinate system if such exists.

(b) Calculate its minimum length. For long lines this should be along the great circle through its end points. For short lines, the length in the coordinate plane is adequate. The lengths thus calculated can be used as a measure of the effect of devious routing. Note, in ground surveying for pipelines, it is common practice to work with slope chained lengths. This sometimes presents problems in mapping.

(c) The line is then laid down on the best available maps. The features along the line should then be examined in detail.

These include relief, streams, swamps, and population centres as major items to consider. The line is then shifted in such a manner as to avoid obvious bad spots. In general, the purpose of this exercise is to determine the route that should be examined by aerial photography and to establish the base for aerial mapping. If it is necessary to shift a portion of the line a considerable distance, it is best done by starting as far back along the line as is practical.

If suitable maps are not available, as is the case in arctic regions, then hopefully existing aerial photos are available for this purpose. The width of the corridor to be examined may be much wider in arctic regions than in warmer and better mapped areas.

(d) Having determined a flight path, the corridor should then be photographed.

(e) When the aerial photographs are ready for use the route can be transferred to these and examined stereoscopically and further adjusted.

(f) The aerial photographs can now be put together to form a mosaic strip of the corridor. The route is established on this mosaic and a plane map is made using an optical plotter

which will enlarge the scale of the mosaic to about one inch equals four hundred feet. (1" = 400')

(g) This map is then examined and the best possible alignment drawn on it. At this stage, it is highly desirable to make a full ground reconnaissance. In addition to the aerial photographs, the line should be examined from the air by low-level visual observation and from the ground by looking at doubtful areas.

(h) The gound reconnaissance should make particular note of the land use with observations as to its potential future use.

Also any obvious effect on the environment or the ecology of the region should be noted. At this stage of the investigation it will probably be wise to make use of competent ecologists and environment impact specialists, as these are key words at any public hearing.

(i) The large scale maps and the aerial photographs are then used for the limited title search.

(j) The aerial photographs should be examined in detail by a competent photogeologist who will assess the geophysical factors which may affect the route selected.

The line should be routed in such a way that underlying

rock and difficult construction features can be minimized or avoided. In arctic regions, other factors such as permafrost, erosion and flooding may affect routing. Sometimes such interpretation may necessitate a re-survey of part of the line to obtain the most economical route. In the case of some routes selected in the Arctic or sub-Arctic a mile by mile geophysical examination should be conducted to determine the prevailing construction difficulties.

(k) In civilized areas, the most important thing to consider is land use, both present and future potential.

(l) If the pipeline is to be used to transport a non-contaminating material such as clean water, it presents a minimum potential hazard. If it is to carry crude or refined hydrocarbons, or natural gas, then the effect of a leak or break must be considered. At the present time, most countries have rules and regulations regarding the location of pipelines. These must be carefully followed. In a number of instances, the condition of the right-of-way after construction is specified. These conditions may affect the routing.

(m) In civilized areas, the cost of the pipeline easement can affect the routing. In the earlier days of pipeline construction, long lines were usually constructed in wilderness or sparsely populated areas and the cost of right-of-way easements was negligible in comparison to the cost

of construction. In the densily populated areas traversed by some pipelines today, this is not true. If the line crosses open farm land very little damage results and the cost is usually quite nominal. If the land is near a densily populated area, the cost of an easement may equal or exceed the nominal value of the land. Sometimes it is economical to let the route follow a random course which parallels the property ownership lines. Occasionally the cost can be reduced by following existing rights-of-way such as other pipelines, highways, railways, power lines or other established corridors.

(n) In wilderness and arctic areas the route is largely determined by natural features such as mountains, streams, rock, swamps, muskeg, permafrost, and the ecological balance. In some areas where the ecology is delicately balanced the effect of construction requirements and the potential hazard from leaks or spills must be considered. In many parts of the North American Continent, the wild life, such as muskrats and other fur bearing animals can affect location and construction methods. In all areas, game refuges, parks, historic sites and other designated areas must be avoided if possible.

(o) Very long and very large diameter pipelines, such as presently proposed by various groups to bring oil and gas from the far north, require extensive studies on construction methods,

design requirements, environmental impact, ecology and communications. Such projects require many years and expenditures of millions of dollars before construction can begin.

SOME PROBLEMS IN POPULATED AREAS

The greatest potential problems in populated areas are the structures which have been constructed by and occupied by people. These include houses, plants, railroads, power lines and city streets. Pipelines in and near cities must contend with and avoid some or all of these. Such items seriously affect pipeline routing as well as construction methods.

SOME PROBLEMS IN ARCTIC AREAS

Before going into detail for these areas it will be best to define certain terms which have had limited use by pipeline location people.

Permafrost

General Philosphy

Permafrost is a term, first used some 30 years ago, which describes the thermal condition of earth materials when their temperature remains continuously below 32°F for a year or longer. This term does not define the earth materials which

may be solid rock, gravel, sand, silt, clay, ice or any mixture of these materials. Permafrost develops where a negative heat imbalance occurs at the ground surface, resulting in a depth of penetration of winter freezing which exceeds the depth of summer thawing. Ice is an important component of permafrost, however, all water in the gound does not freeze at 32°F if it contains impurities or is under pressure. Permafrost underlies over 50 percent of the land mass of Canada and Alaska and those areas where the necessary thermal conditions at the ground surface exist are generally divided into two zones as follows:

Continuous Permafrost

In this zone, permafrost exists everywhere beneath the ground surface except in newly deposited unconsolidate sediments, and ranges in thickness from 200 feet at the southern boundary to over 1,000 feet in the Arctic Islands. The depth of thaw (Active Layer) varies from a few inches to about 4 feet.

DISCONTINUOUS Permafrost Line

The zone extends from the southern boundary to the continuous zone, southward until the mean annual ground temperature isotherm is just above 32°F. In this zone, frozen and unfrozen layers exist together, the layers are thin and very scattered at the southern limit, they increase in size, frequency and thickness northward. Along the southern fringe, the occurrences have been associated with the north facing slopes of east-west valleys or

along heavy forested stream banks. Northward, it gradually becomes more wide-spread, being associated with a greater variety of terrain types. In this zone, the active layer, up to 10 feet in depth along the southern limit, does not always extend to the permafrost table. The active layer is the layer of earth materials between the permafrost table and the surface which thaws in summer and freezes in winter. Its depth depends on the same climatic conditions that affect the permafrost.

Climate is a basic factor in the formation and existance of permafrost; and the thickness of the permafrost and of the active layer is mainly influenced by air temperatures. However, time, relief (slope and aspect), vegetation, drainage, snow cover and soil types also have a bearing on these thicknesses. Changes in any of these conditions can result in changes to the active layer and permafrost regime. The effects resulting from changes to this regime are also related to the types of materials, depth of active layer, extent of permafrost and ice content of the soils.

GEOTECHNICAL CRITERIA

General

Since route selection in the arctic can depend to a great extent on the stability of the soil and the required methods of construction, an extensive geotechnical study must be made. In order to reach a decision as to whether a warm pipeline can be

supported by a thawing foundation or will have to be piled or insulated to avoid the thawing process, it is necessary to assess the engineering properties of the soil and relate them to the pipeline properties. Although it is relatively easy to calculate the maximum deflections which can be attained by various dimensions of pipes, it is difficult to relate these deflections with a high degree of accuracy to the permafrost soils due to the natural heterogeneity of the soil-ice matrices.

In order to appreciate the level of geotechnical knowledge economically attainable, it is advantageous to examine a possible approach method for route selection in the arctic. One of the major objectives of this selection would be to obtain sufficient geotechnical data to allow the selection of the most economic method of foundation design for the pipeline. Although the economics of each type of construction do not appear to be established clearly for arctic conditions, it does appear desirable from a pipe security point of view to bury as much of the pipe as possible. This results in the requirement for knowledge of the behaviour of the various permafrost soils as the thaw front advances.

Feasibility Study Approach

Initially, the route selection method is similar to the approach taken in temperate regions. The route is provisionally selected based on consideration of distance, topography and minimum disturbance to areas such as wildlife reserves, migrating areas, unstable zones, etc.

The route is then plotted on a series of mosaics, the band of coverage varying in width depending on topography and possible alternative route sections. In addition the band covered has to be sufficiently broad to allow a regional interpretation of the geology.

The route is then divided into a series of physiographic divisions which have approximately the same climatic conditions within each division. These divisions must be so structured that areas of similar geologic origin within each unit will consist of approximately the same constituent materials. The divisions must then be analyzed in broad terms with reference to large scale topography and major landforms in the region, climatic and permafrost conditions, vegetation and resources, and any other special conditions which may be peculiar to that division. The special conditions include such items as potential aquifers, ice wedges, pingos, river bank erosion, etc.

Within each of the physiographic divisions a photogeologic analysis should be carried out. As a result of this analysis all the overburden or rock within the division should be classified as to its geologic origin. As part of this classification, each area will have a description of depositional environment, stratigraphy limits, permafrost occurrence (with associated resulting features) topography, and vegetation. In addition to the above observations, a range of engineering characteristics including plasticity, organic content, slope stability for both frozen and thawed conditions, settlement potential on thawing and availability of granular borrow materials can be estimated.

Drainage characteristics should be observed. These include water course types, drainage patterns and sedimentation and erosion character of streams and rivers. Evidence of bank instability along major streams should also be noted.

Based on the observed features and whatever other geotechnical information which may be available from other studies in the area, conjectural logs or soils may be formed. The logs will have wide ranges of thickness for most soil layers and a broad classification for each soil type. From an engineering standpoint their major value consists of supplying information on conditions which might be encountered during construction and in defining the very good conditions (such as low ice content granular deposits) and the very high ice content areas. In order to upgrade the quality of this information for engineering usefulness, a series of boreholes should then be drilled at various pre-selected locations. Based on the results from these investigations, the conjectural borehole logs can be refined and the engineering characteristics of the various soils be re-defined to allow a more reasonable estimate of construction problems which might be encountered.

The geologic units can then be divided into three types based on their foundation suitability.

Type 1 soils where the ice content is low (or the soils unfrozen) in which little or no settlement will occur on thawing.

Type 2 soils where the ice content is sufficiently high and variable to result in possible pipe stress if the pipe is buried.

Type 3 soils where the ice content is high and variable.

Limitations of Geotechnical Knowledge

Even in areas where conditions are uniform and the climate is temperate the question of how far borehole definition can be extrapolated is difficult to answer. This question is often resolved for structures with a small plan area by drilling a borehole under each critical area to ensure overall safety of a structure. For a pipeline this is obviously not economical.

It is difficult to define the accuracy of information which has been extrapolated in a regional sense to a large area from a small number of boreholes. This is particularly true when the basis for extrapolation is a landform, vegetation, climate, drainage, etc. Although the information may be accurate in a regional sense, from an engineering standpoint, it may be far from adequate.

In progressing from a feasibility study stage to design and construction, one must consider methods of raising the level of geotechnical information.

The amount of investigation required to elevate the level of geotechnical knowledge from a feasibility level to that required

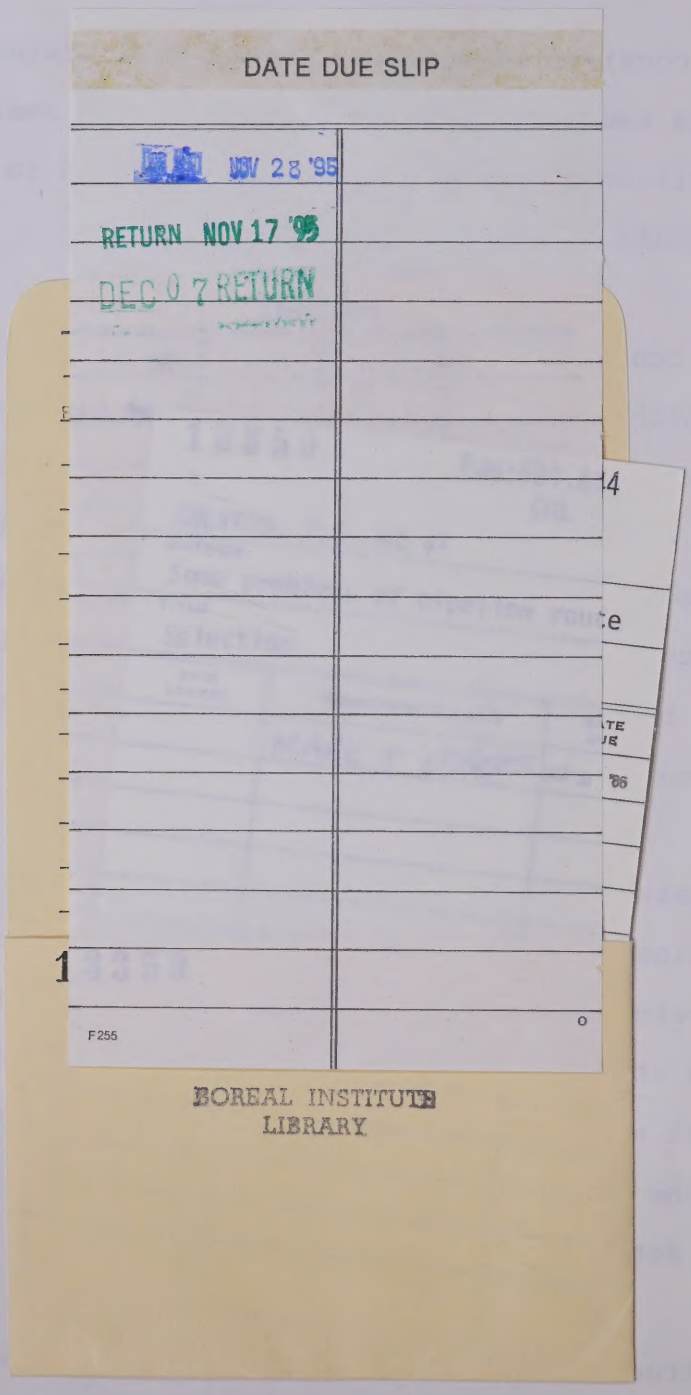
for design and construction is considered in the previously defined soil groups as follows:

Type 1 - which consists of low-ice-content well drained soils such as kames, eskers and some tills - a small number of additional boreholes would be required to confirm the limits of geologic units.

Type 2 - which consists of units in which burial is a possibility but which require further analysis to delineate the engineering properties of the soils within the units. These units would require a significant amount of additional drilling to define more accurately settlement characteristics. The object of this investigation would be to reduce this "grey area" rather than eliminate it.

Type 3 - consists of units in which settlement is so large that the pipe, if buried, would be overstressed or where an undersirably large trough would develop at the surface. These units are already defined as unsuitable for burial and, as such, boreholes would be required only for the definition of parameters for such items as pile design.

Prior to construction, a field evaluation of the units in which burial is proposed would be required. This would consist of an examination of the right-of-way in these units, possibly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using a remote sensing unit, to detect any major ice masses which might have been missed in earlier studies.

A second phase of this study might be required if the remote sensing units were not sufficiently accurate for the marginal terrains. This would consist of drilling holes in doubtful areas to the anticipated full depth of the thaw bulb. The settlement could then be evaluated in these and thus the mode of construction confirmed. Although it would appear that this method would require a great number of holes, it is possible that it would be used over a relatively short distance of line, the grey area having previously been reduced to a minimum.

SUMMARY

Pipelines must be routed in such a manner as to cause the least disturbance to the environment, the ecology, and the populations. This may require extensive studies both in wilderness areas and in populated areas. In all cases the possible effects of accidents must be evaluated.

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